GEOLOGIC RESOURCE MONITORING PARAMETERS

Frozen Ground Activity

Brief Description: Permafrost is present in 13% (18 million km2) of the world's soils . In permafrost and other cryogenic (periglacial) areas and in temperate regions where there is extensive seasonal freezing and thawing of soils, a wide range of processes lead to a variety of surface expressions, many of which have profound effects on human structures and settlements, as well as on ecosystems. These sensitive periglacial features are found around glaciers, in high mountains (even at low-latitudes) and throughout polar regions. The development (aggradation) or degradation of permafrost is a sensitive and early indicator of climate change [see subsurface temperature regime]. Important geological parameters related to permafrost regions include:

1. Active layer thickness: The thickness of the active layer, the zone of annual freezing and thawing above permafrost, determines not only the overall strength of the ground but also many of the physical and biological processes that take place in periglacial terrains. Soil moisture and temperature, lithology and landscape morphology exercise important controls on active layer thickness. Soil moisture and temperature depend largely on climatic factors, so that if the mean annual air temperature rises several degrees Celsius, the thickness of the active layer may change over time periods of years to decades.
2. Frost heaving is a basic physical process associated both with near surface winter freezing and with deeper permafrost aggradation. Frost heaving can displace buildings, roads, pipelines, drainage systems and other structures. Many frozen soils have a much greater water content than their dry equivalents and undergo a local 10-20% expansion in soil volume during freezing. The frost heave process and the consequences of thawing are of great importance in the development of many of the unique features of cold terrains, including perennial hummocks and seasonal mounds, patterned ground, palsas and pingos.
3. Frost cracks are steep fractures formed by thermal contraction in rock or frozen ground with substantial ice content. They commonly intersect to create polygonal patterns, which may lead to the formation of wedges of ice and surficial material. The frequency of cracking is linked to the intensity of winter cold. Where climate is warming, ice-wedge casts replace ice wedges over periods of decades.
4. Icings are sheetlike masses of layered ice formed on the ground surface, or on river or lake ice, by freezing successive flows of water that may seep from the ground, flow from a spring or emerge from below river or lake ice through fractures. The intensity of icings in the southern portions of the permafrost zone may change annually, increasing with colder winters and lower snow cover combined with autumnal precipitation. Further north, icings increase in size but decrease in number when the climate cools, and vice-versa when it warms.
5. Thermoerosion refers to erosion by water combined with its thermal effect on frozen ground. Small channels can develop into gullies up to several kms in length, growing at rates of 10-20 m/year, and in sandy deposits, as fast as 1 m/hour. The main climatic factors controlling the intensity of thermoerosion are snow melt regime and summer precipitation.
6. Thermokarst refers to a range of features formed in areas of low relief when permafrost with excess ice thaws. These are unevenly distributed and include hummocks and mounds, water-filled depressions, ‘drunken’ forests, mud flows on sloping ground, new fens, and other forms of thaw settlement that account for many of the geotechnical and engineering problems encountered in periglacial landscapes. Even where repeated ground freezing takes place, thermokarst features, once formed, are likely to persist.
7. Permafrost terrains are characterized by a wide range of slow downslope movements involving creep, such as rock glaciers and gelifluction, and by more rapid landslides and snow avalanches [see slope failure].

Significance: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands, mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further climate change by the release of carbon and other greenhouse gases during thawing. It is estimated that nearly 1/4 of the world's terrestrial carbon is tied up in dead organic mater in the active layer and in permafrost: long-term climate warming would facilitate decomposition and drying, releasing huge quantities of methane and CO2 [see wetlands extent, structure and hydrology]. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

Environment where Applicable: High and medium latitudes and high altitudes (arctic and cold deserts, tundra, taiga, mountains) where ground freezing is extensive.

Types of Monitoring Sites: Vegetated polar regions, high altitude locations, areas of obvious disturbance of the active layer (e.g. icings, polygons, failing slopes, areas of frost heaving).

Method of Measurement: There are many approaches to the monitoring of permafrost activity:
1. Active layer thickness can be easily measured, except in coarse and bouldery soils, by probing with a steel rod. Geophysical techniques such as ground probing radar can be useful for detecting relatively large changes in thaw depth. More accurate measurements may be obtained using relatively inexpensive frost tubes, which can be utilized over any time interval, though, ideally, active layer data should be collected at regular intervals from time of snowmelt until annual freezeup. Soil temperature probes are also useful [see subsurface temperature regime].
2. Frost heaving can be determined by scribers mounted on the outside of frost tubes, or by other scriber recorders, which permit maximum annual heave to be measured. Heaving associated with deeper freezing (permafrost aggradation) can be assessed through repeated levelling of an area. In the case of drained basins where aggradation can be quite rapid annual determinations are best, but, in general, surveys over periods of decades will suffice.
3. Frost crack patterns on ice wedges can be measured annually by the use of breaking cables that record crack opening and spreading.
4. The persistence of icings through a summer is an indication of the relative warmth of the season. In colder years icings persist. Where springs are common, change over years to decades can be deduced from sequential air photos or satellite images.
5. The frequency and distribution of thermoerosion and thermokarst provide indicators of regional change, readily assessed over periods of years to several decades with sequential air photos of satellite images.
6. Slope stability and creep can be measured by installed inclinometer tubes, though these may become inoperable after considerable creep has taken place.

Frequency of Measurement: Depends on the kind of disturbance being monitored, as detailed above. Certain features need to be checked weekly to several times during a summer season, others on an annual or decadal basis.

Limitations of Data and Monitoring: It is difficult to do field work in areas of active thawing without disturbing mobile soils and landforms or without endangering sensitive ecosystems. In response to highly variable local conditions, grids installed to monitor polygon development should be left in place or extended from year to year.

Possible Thresholds: The freeze-thaw transition is a major threshold that, once crossed, may lead to the development of various landforms, some of which (e.g. thermokarst) are irreversible at least on time scales of less than centuries. Many frozen ground features are closely linked to the ground thermal regime, and changes in moisture conditions or in vegetation or snow cover can offset changes in air temperature [see subsurface temperature regime].

Key References:

Romanovskii, N., G.F.Gravis, M.O.Leibman & E.Melnikov 1996. Periglacial processes as geoindicators in the cryolithozone. In Berger, A.R. & W.J.Iams (eds). Geoindicators: Assessing rapid environmental changes in earth systems:33-54. Rotterdam: A.A. Balkema. (see also paper by Rasch et al.)

Washburn, A.L. 1980. Geocryology. New York, Wiley & Sons, Halstead Press.

Williams, P.J. & M.W.Smith 1989. The frozen Earth - fundamentals of geocryology. Cambridge: Cambridge University Press.

Related Environmental and Geological Issues: Thawing effects are hazardous to animal and human habitation, and permafrost ecosystems are easily disturbed.

Overall Assessment: Frozen ground (permafrost and periglacial) activity is sensitive to local climate, hydrology, and vegetation cover. Apart from the thickness of the active layer, which is a most useful indicator of local environmental change, most frozen ground features reflect regional change about the freezing point and require much effort to monitor.

Source: This summary of monitoring parameters has been adapted from the Geoindicator Checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Geoindicators include 27 earth system processes and phenomena that are liable to change in less than a century in magnitude, direction, or rate to an extent that may be significant for environmental sustainability and ecological health. Geoindicators were developed as tools to assist in integrated assessments of natural environments and ecosystems, as well as for state-of-the-environment reporting. Some general references useful for many geoindicators are listed here:

Berger, A.R. & W.J.Iams (eds.) 1996. Geoindicators: assessing rapid environmental change in earth systems. Rotterdam: Balkema. The scientific and policy background to geoindicators, including the first formal publication of the geoindicator checklist.

Goudie, A. 1990. Geomorphological techniques. Second Edition. London: Allen & Unwin. A comprehensive review of techniques that have been employed in studies of drainage basins, rivers, hillslopes, glaciers and other landforms.

Gregory, K.J. & D.E.Walling (eds) 1987. Human activity and environmental processes. New York: John Wiley. Precipitation; hydrological, coastal and ocean processes; lacustrine systems; slopes and weathering; river channels; permafrost; land subsidence; soil profiles, erosion and conservation; impacts on vegetation and animals; desertification.

Nuhfer, E.B., R.J.Proctor & P.H.Moser 1993. The citizens' guide to geologic hazards. American Institute for Professional Geologists (7828 Vance Drive, Ste 103, Arvada CO 80003, USA). A very useful summary of a wide range of natural hazards.